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ADVANCED SEISMOLOGICAL RESEARCH AND IMPROVED YIELD DETERMINATION

J. T. Cherry

SYSTEMS, SCIENCE AND SOFTWARE
P.O. Box 1620
La Jolla, California 92038

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This report summarizes work performed by S-CUBED involving the effects of spall and nonisotropic prestress on m_b and M_s, the analysis of the physical basis for explosion and earthquake discriminants, and the investigation of establishing a remote computer link using an error controller.

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Principal Investigator and Phone No.

Dr. J. Theodore Cherry, (714) 453-0060

Project Scientist and Phone No.

Mr. Brian W. Barker, (202) 325-7581

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TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

I. INTRODUCTION

The objective of the S-CUBED (S^3) research program is to extend our present understanding of the generation, propagation, detection and analysis of seismic waves by both underground explosions and earthquake sources. The goal is to improve the United States' ability to monitor compliance with treaties limiting the yields of underground nuclear explosions. This report covers work performed at S^3 during the twelve month contract period between 1 October 1980 and 1 October 1981 under Contract Number F08606-79-C-0008 (VSC Project VT/0712).

Specific topics summarized in the following sections are:

~~Task 4.1~~ The identification of the critical explosion/earthquake source and geologic parameters effecting detection, discrimination and yield estimation;

~~Task 4.2~~ The evaluation of suites of events in terms of our ability to predict the observed body waves and surface waves from these events which travel over previously uncalibrated paths; and

~~Task 4.4~~ The support of remote seismic research involving the development and acquisition of remote hardware necessary to optimize utilization of the computer systems at the Seismic Research Center. (SRC).

II. EXPLOSION AND EARTHQUAKE CALCULATIONS (Task 4.1)

During the contract period we have investigated the effects of spall and nonisotropic prestress on m_b and M_s, provided a theoretical basis for the m_b:M_s and Variable Frequency Magnitude (VFM) earthquake/explosion discriminants, and compared our dynamic fault model with uniform-kinematic fault models. The topical reports, including abstracts, submitted are as follows:

1. SURFACE WAVES FROM UNDERGROUND EXPLOSIONS WITH SPALL: ANALYSIS OF ELASTIC AND NONLINEAR SOURCE MODELS BY S. M. DAY, N. RIMER, AND J. T. CHERRY, VSC-TR-82-11 (SSS-R-82-5212)

Abstract

Anomalous surface wave observations from underground explosions have been widely attributed to the phenomenon of spall, i.e., the detachment and subsequent slapdown of near-surface layers in response to explosion-induced tensile stresses. We argue, on the basis of a simple equivalent-force model, that, while spall can enhance explosion surface waves at very short periods, it cannot contribute significantly to the teleseismic surface waves radiated by underground explosions at periods exceeding about 10 seconds. Previous theoretical results to the contrary are in error, having been based on source models which do not conserve momentum.

A nonlinear, two-dimensional (axisymmetric) finite difference simulation of a buried explosion in granite further supports the conclusion that spall cannot contribute to long-period surface waves. The simulation exhibits extensive spall; nonetheless, predicted fundamental mode Rayleigh wave spectra are nearly identical to those obtained from a spherically symmetric simulation (which does not include spall), at periods exceeding about 10 seconds. At shorter periods, the two-dimensional simulation predicts some Rayleigh wave enhancement, compared to the one-dimensional simulation.

The maximum enhancement, about a factor of 2, occurs at a period of approximately 2.5 seconds. Synthetic long-period Rayleigh wave seismograms, at 3000 km range, show no perceptible phase or amplitude anomalies due to spall. These results are in excellent agreement with the predictions of the equivalent-force model.

2. THREE-DIMENSIONAL FINITE DIFFERENCE SIMULATION OF FAULT DYNAMICS: RECTANGULAR FAULTS WITH FIXED RUPTURE VELOCITY BY S. M. DAY, VSC-TR-81-28 (SSS-R-81-5158)

Abstract

We analyze three-dimensional finite difference solutions for a simple shear-crack model of faulting to determine the effects of fault length and width on the earthquake slip function. The fault model is dynamic, with only rupture velocity, fault dimensions, and dynamic stress-drop prescribed. The numerical solutions are accurate for frequencies up to 5 Hz, and are combined with asymptotic results for shear cracks in order to characterize the slip function at higher frequencies.

Near the hypocenter, the slip velocity exhibits a square root singularity whose intensity increases with hypocentral distance. At distances greater than the fault width, w, growth of the velocity intensity ceases, and the slip function becomes nearly invariant with the distance along the fault length. Close-form expressions are developed for the dependence of static slip (s_∞), slip rise time (T_r), and slip velocity intensity (V) on fault geometry. Along the centerline of a long, narrow fault, at hypocentral distances exceeding w, these expressions reduce to $s_\infty \approx w\Delta\tau/\mu$, $T_R \approx 0.5\ w/\upsilon_R$, and $V \approx \sqrt{w/2}\ \upsilon_R\ \Delta\tau/\mu$, where $\Delta\tau$ is the dynamic stress drop, μ the shear modulus, and υ_R the rupture velocity.

The numerical results imply that uniform-dislocation kinematic earthquake models in which slip is represented by a ramp time-function will underpredict high-frequency ground motion relative to low-frequency ground motion. A further implication of the numerical solutions is that the nature of inelastic processes at the advancing edge of a long fault will depend on fault width, but will be independent of rupture length.

In addition, we have submitted expanded abstracts which were published in the VSC Research Conference Program with Abstracts, VSC-TR-82-1. The titles of the talks presented at the conference were:

1. PHYSICAL BASIS OF m_b:M_s AND VFM METHODS FOR EARTHQUAKE/EXPLOSION DISCRIMINATION BY J. L. STEVENS AND S. M. DAY.

2. THE SHAGAN RIVER STORY (THE EFFECTS OF SPALL AND PRESTRESS ON m_b AND M_s) BY S. M. DAY, N. RIMER, J. T. CHERRY, AND J. L. STEVENS.

III. THE EVALUATION OF SUITES OF EVENTS (Task 4.2)

During the contract period we have developed an analytic model for explosion induced tectonic strain release and used the model to explain anomalous body waves and surface waves from explosions at NTS and Eastern Kazakh. The following topical report has been submitted.

1. A MODEL FOR TECTONIC STRAIN RELEASE FROM EXPLOSIONS IN COMPLEX PRESTRESS FIELDS APPLIED TO ANOMALOUS SEISMIC WAVES FROM NTS AND EASTERN KAZAKH EXPLOSIONS BY J. L. STEVENS, SSS-R-82-5358

Abstract

Anomalous surface waves including Love waves and phase reversed Rayleigh waves have been observed from explosions at NTS and from the eastern Kazakh areas of the Soviet Union. In this report we use a linear model for tectonic strain release to estimate the amount and type of prestress required to produce these anomalies. An important use of these results is to guide the input to fully nonlinear simulations of an explosion detonated in a prestressed environment.

Tectonic strain release adds energy to the explosion component of the seismic radiation because elastic energy stored in the medium is released when a zone of weakened material strength is created by the explosion. In the model, this zone is treated as if it were a spherical cavity with the dimensions of the explosion-produced failure zone. This effective cavity radius requires independent constraints which can be provided by nonlinear simulations.

General conclusions are as follows:

In the presence of stress concentrations, tectonic release enhances high frequency radiation in preferred directions.

Compressive stress concentrations reduce body wave amplitudes while tensile stress concentrations amplify body waves.

Long period tectonic surface waves depend only on the average prestress field and are unaffected by stress heterogeneity.

The tectonic surface waves reduce to a monopol plus a quadrupole field superimposed on the ex sion monopole.

Specific conclusions are as follows:

Rayleigh wave reversals or factor of two e ce-ments (depending on the horizontal prestress being compressive or tensile relative to the hydrostatic prestress) can be obtained with homogeneous or average shear stresses of about 50 bars assuming that the effective cavity radius is equal to the explosion elastic radius.

A maximum local shear stress of about a kilobar is required before the tectonic component of body waves becomes comparable in size to the explosion body waves. The average prestress may be much lower, however.

The anomalous body wave, Love wave and Rayleigh wave radiation from PILEDRIVER can be simultaneously explained by a compressive stress concentration of about a kilobar to the northeast of the explosion.

IV. SUPPORT OF REMOTE SEISMIC RESEARCH (Task 4.4)

For a variety of technical reasons, our hopes to establish a remote link to the SDAC 11/70 computer directly from the La Jolla offices of S-CUBED did not come to fruition. Our concept had been to use a dial-up asynchronous connection rather than a leased and specially conditioned line for economy and versatility. It was to consist of a Tektronix 4014 with hard copy unit in La Jolla, and we wanted also to transmit data at 4800 baud because the principal use of the link was to be seismic waveform analysis, involving the frequent transmission of pictures containing, typically, 50,000 bytes (12 traces, 100 points/trace, 4 bytes/point). This requires approximately 100 seconds at 4800 baud, assuming uninterrupted attention from the originate end of the line.

Dial-up links at 4800 baud, while pushing telemetry technology, are widely used. As with any telemetry system, occasional errors creep into the data, however, and even at a bit error rate of 10^{-7} one expects a 4800 baud link to experience an error every 100 seconds or so. To prevent such errors getting through to the seismogram display, we elected to incorporate a novel hardware element, the Micro 500 Error Controller manufactured by Micom, Inc. The remote link design, as originally proposed, is shown in Figure 4.1.

One further constraint was that the equipment be leased since the remote link was an experimental project, and experienced engineering personnel would be required to maintain the equipment. The lease was arranged through the Apparatus Services Business Division of General Electric with offices and facilities nationwide, in particular, Los Angeles and Baltimore.

Equipment was originially installed in late April, 1981, and by mid-May, it was clear that we were obtaining unsatisfactory performance. Three difficulties were observed:

1. It often took several attempts to establish the connection.

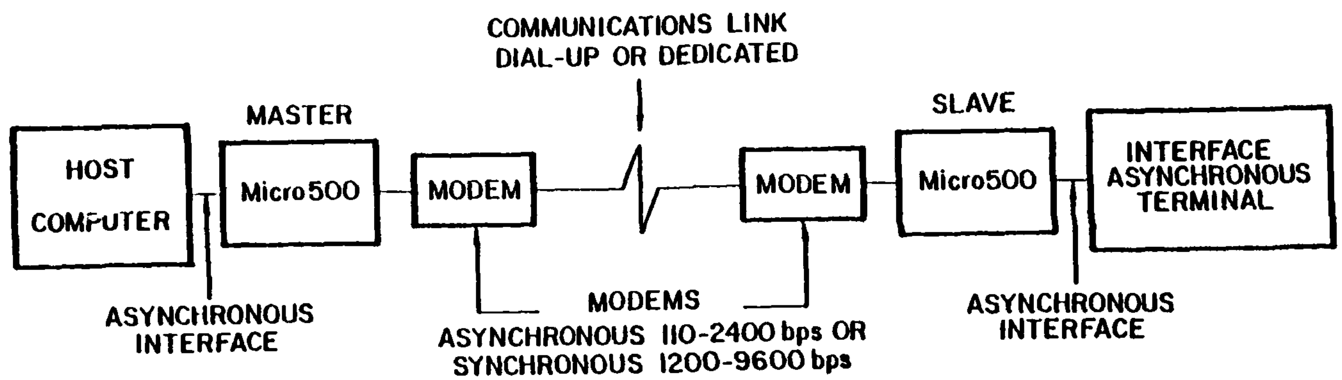

Figure 4.1 Remote link configuration featuring the Micro 500 Error Controller.

2. The Tektronix sometimes changed from graphics to alphanumerics mode (evidence of erroneous data being passed through the Micro 500).

3. The link never was maintained for more than 20 minutes before the system spontaneously lost synchronization.

Then started a nine month struggle to fix the system. The problem was finally diagnosed as an intolerance by the Micro 500 to the link transmission delays caused by the connection being established through a satellite path rather than land lines. Micom provided at least one upgrade to the Micro 500 system (in November, approximately) which still did not yield satisfactory performance. We are told that the latest Micro 500 does work as advertized for both land lines, land based microwaves, and satellite connection, but by December we had abandoned the project so the new generation hardware was not tested.